redistribution of atmospheric mass and non-adiabatic heating during a dipole mode event may result in such an event influencing the countries surrounding the Indian Ocean through atmospheric teleconnections, as evidenced by the northward shift of the Pacific Subtropical High off the Philippines which caused an unusually hot summer in the far east Asian countries in 1994 (refs 27, 28). Some atmospheric general circulation model experiments^{29,30} have demonstrated the important effects of the Indian Ocean SST changes on east African rainfall variability. Further experiments with atmospheric and oceanic models, extended in scope, will be needed to understand the full implications of this hitherto unexplored mode of climate variability. The dipole mode event should also provide a testing ground for coupled ocean-atmosphere models. □

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Tribosphenic mammal from the North American Early Cretaceous

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The main groups of living mammals, marsupials and eutherians, are presumed to have diverged in the Early Cretaceous¹, but their early history and biogeography are poorly understood. Dental remains have suggested that the eutherians may have originated in Asia², spreading to North America in the Late Cretaceous, where an endemic radiation of marsupials was already well underway³. Here I describe a new tribosphenic mammal (a mammal with lower molar heels that are three-cusped and basined) from the Early Cretaceous of North America, based on an unusually complete specimen. The new taxon bears characteristics (molarized last premolar, reduction to three molars) otherwise known only for Eutheria among the tribosphenic mammals. Morphometric analysis and character comparisons show, however, that its molar structure is primitive (and thus phylogenetically uninformative), emphasizing the need for caution in interpretation of isolated teeth. The new mammal is approximately contemporaneous with the oldest known Eutheria from Asia. If it is a eutherian, as is indicated by the available evidence, then this group was far more widely distributed in the Early Cretaceous than previously appreciated. An early presence of Eutheria in North America offers a potential source for the continent's Late Cretaceous radiations, which have, in part, proven difficult to relate to contemporary taxa in Asia.

Class Mammalia

Infralegion Tribosphenida, Order and Family Uncertain

Montanalestes keebleri gen. et sp. nov.

Etymology. Montana: the state of origin; lestes (Greek): robber; *keebleri*: in honour of the Keebler family of Billings, Montana, in recognition of its support for field parties of the Oklahoma Museum of Natural History (OMNH).

Holotype. OMNH 60793, associated dentaries with right p3–5, m1–3 (terminology follows ref. 4), and alveoli for p2; and left p5, m1–3 (Fig. 1).

Locality and Horizon. OMNH V1156, basal unit VII (ref. 5), Cloverly Formation (Aptian–Albian; ~110 Myr); Carbon County, Montana, USA.

Diagnosis. Differs from primitive Tribosphenida (for example, *Kermackia*), in so far as is known, in having a semimolarized last premolar (lingually placed paraconid, incipient talonid basin, metaconid present) and only three molars; molars differ in having a broader, more fully basined talonid with three cusps consistently present. Differs from early marsupials and marsupial-like taxa⁶ in postcanine tooth formula and in having semimolarized last premolar and a smaller size differential between m1–2; lower molars differ in lacking a labial postcingulid and in having a greater trigonid–talonid height differential, narrower talonid and a hypoconulid that is not lingually situated. Differs from *Slaughteria*⁷ in having a semimolarized, less anteroposteriorly compressed last premolar; molars differ in having a smaller size differential between m1–2, no lingual knob on anteroconulid, more acute trigonid angle on m1 and taller paraconid relative to metaconid. Similar to early Eutheria in postcanine tooth formula (four or more premolars, three molars) and semimolarized last premolar; differs from most comparable taxon, *Prokennalestes*⁸, in having salient lingual cingulids on the lower premolars and stronger paraconid and metaconid on p5, the former more lingually placed. Lower molars differ from those of *Prokennalestes* in having sequential length

increase from first to third, taller paraconid, and greater height differential between trigonid and talonid and between protoconid and metaconid, more distinct and anteriorly placed entoconid, and hypoconulid more projecting on m1–2.

Description. The Meckelian groove (Fig. 2) and labial mandibular foramen, found in a number of Cretaceous mammals including presumed eutherians⁸, are absent. A roughened depression at the junction of the ascending and horizontal rami may indicate the presence of the coronoid, a presumed primitive condition with a broad distribution among early mammals, including some eutherians⁸. The angular process is elongate, hook-like, projects posteriorly and is in-turned medially, as in primitive Tribosphenida

Figure 1 *Montanalestes keebleri* gen. et sp. nov., OMNH 60793. **a**, Stereopairs of p4–m3 (other parts of dentition and mandible omitted for clarity) in labial (left) and lingual (right) views. **b**, restored right mandible and dentition in labial (top), occlusal (middle) and lingual (bottom) views.

Figure 2 Jaws of Cretaceous tribosphenic mammals, showing distribution of selected tooth and jaw characters (some restored after refs given in Supplementary Information). *Kielantherium* is a plesiomorphic tribosphenidan of uncertain affinities¹⁴; *Kokopellia* is a marsupial or close relative⁶; and *Prokennalestes*⁸, *Otlestes*¹⁶ and *Asioryctes*²² are Cretaceous eutherians. 1, Talonid. Primitively (*Kielantherium*), this is small, poorly basined and bears only two cusps; in remaining taxa it is broader and well basined, with three cusps¹¹. 2, Coronoid bone. This element, or a facet indicating its presence, is a primitive feature presumably lost early in marsupial history and independently among eutherians, but retained in many Cretaceous mammals^{6,8}. 3, Meckelian groove (uncertain in *Otlestes*¹⁶ and *Kokopellia*⁶). This feature is another primitive character retained in some early eutherians and other Mesozoic mammals^{8,14,23}. 4, Premolar count. The primitive counts for premolars and molars are uncertain, depending partly on varying interpretation and relevance of non-tribosphenic *Peramus*, and partly on disputed homologies^{12,24}. At least four premolars are present in *Peramus* and *Kielantherium*, whereas deltatheroidans and marsupials have only three^{11,13–15}. The widespread occurrence of at least four in early eutherians is assumed to be primitive. 5, Last premolar. This tooth is simple in *Kokopellia*, marsupials and most Mesozoic mammals; by contrast, the premolars and molars of eutherians generally form a more evenly graded series, with the last premolar tending toward a semimolariform appearance^{8,12}. *Montanalestes* appears to be more advanced than the rather variable¹⁰ *Prokennalestes*, but the talonid and metaconid are not as well developed as in somewhat younger *Otlestes*¹⁶. 6, Molar count. This is uncertain for many early tribosphenidans⁷. *Kielantherium*, like marsupials and deltatheroidans, has four; *Montanalestes* is similar to eutherians in having only three molars, presumably an advanced condition^{11,12,15}. ?, alveolus for tooth of uncertain identity; p, premolar (or alveoli (arrows) documenting presence of a premolar).

generally⁹. At least four premolars are present; the relatively small size of p3 is similar to those in some Cretaceous eutherians that have five premolars¹⁰. The premolar–molar series intergrade: p5 is semimolariform, with a lingually placed paraconid; a metaconid that is clear but that is placed low on the crown and is not so lingually situated; and a small talonid basin enclosed lingually by the cingulum (although only one talonid cusp is present). The molars are virtually unworn and facets are poorly developed. They are advanced with respect to primitive tribosphenidans (Fig. 2) in having a well developed, basined, tricuspid talonid. The molars generally resemble those of pappotheriids and some early eutherians¹¹, although the latter tend to have a reduced paraconid¹². Molars of *Montanalestes* are unusual in having a relatively strong paraconid and a sequential increase in length from m1–3.

Montanalestes is undoubtedly a tribosphenic mammal, as shown by the broad, basined, three-cusped molar talonids¹³, and it is advanced with respect to dentally primitive taxa such as *Kielantherium*¹⁴ in various features (Fig. 2). *Montanalestes* is clearly not a marsupial: it retains more than three premolars, lacks specialized molar characteristics^{6,12,15} and has a molarized distal premolar^{11,12}, among other features. Eutherian affinities are, however, suggested by dental characteristics. The presence of four

Figure 3 Comparison of lower molar shape in selected Cretaceous tribosphenic mammals and the eupantothere *Peramus*. Measurements and methodology follow ref. 11; data from this source has been standardized and variation due to size has been removed. Plot shows the first two axes of a principal components analysis. Positive scores (representing advanced conditions) on axis 1 reflect mainly increased length of the posthypocristid and width of the talonid, and relatively lower protoconid; this shape factor serves mainly to distinguish marsupials from eutherians and primitive tribosphenic/non-tribosphenic mammals. Positive scores on axis 2 reflect increased trigonid width, anteroposterior compression of the trigonid and lowered height differential between protoconid and metaconid. This shape factor generally distinguishes non-tribosphenic and some primitive tribosphenic mammals from the more advanced marsupials and, especially, eutherians. Taxa in the middle of the graph (for example, *Montanalestes* (8), *Pappotherium* (7), *Procerberus* (15)) have molars that, in terms of the two shape factors, are structurally antecedent to both marsupials and eutherians. Note placement and clustering of *Deltatheridium* (4) with primitive taxa (1–5), and placement of *Holoclemensia* (9) and *Kokopellia* (12) with respect to undoubted eutherians and marsupials. Circles, non-tribosphenic taxa and Theria of metatherian–eutherian grade; triangles, marsupials; squares, eutherians. 1, *Peramus*; 2, *Hypomylos*; 3, *Kielantherium*; 4, *Deltatheridium*; 5, *Kermackia*; 6, *Potamotelses*; 7, *Pappotherium*; 8, *Montanalestes*; 9, *Holoclemensia*; 10, *Didelphodon vorax*; 11, *Pediomys elegans*; 12, *Kokopellia*; 13, *Glasbius*; 14, *Alphadon marshi*; 15, *Procerberus*; 16, *Prokennalestes* spp.; 17, *Batodon*; 18, *Paranyctoides* spp.; 19, *Kennalestes*; 20, *Gallolestes pachymandibularis*; 21, *Gypsonictops hypoconus*; 22, *Cimolestes cerebroides*; 23, *Ottestes*; 24, *Asioryctes*; 25, *Purgatorius unio*; 26, *Cimolestes incisus*; 27, *C. magnus*; 28, *Protungulatum* spp.; 29, *Cimolestes propaleoryctes*; 30, *Zalambdalestes lechei*.

molars appears to be primitive for tribosphenic mammals^{11,12,15}; *Montanalestes* shares the condition seen in eutherians, a presumed reduction to three molars. The premolars of most early mammals are simple and form a sharp break with the molar series, whereas eutherians are presumed to be derived in having premolar–molar series intergrade, with a tendency for the last premolar to be somewhat molariform^{8,12}. *Montanalestes* is similar to eutherians in this respect: the last premolar bears a strong, lingually placed paraconid, a metaconid and a slightly basined talonid, all features commonly seen in premolars undergoing molarization. By comparison to *Prokennalestes* and other early Eutheria^{2,8,11,16}, *Montanalestes* presents a mixture of advanced (for example, metaconid on p5, loss of Meckelian groove) and primitive (for example, unreduced paraconid) features. Molar structure is of particular interest in this context because it has traditionally been emphasised in interpretation of early mammal radiations^{11,17}. Morphometric analysis shows that marsupials and dentally advanced, Late Cretaceous eutherians can be recognized in the basis of lower molar shape factors; plesiomorphic tribosphenidans are also distinct (Fig. 3). However, certain early tribosphenidans, *Montanalestes* and some early eutherians are structurally appropriate antecedents to both major groups of tribosphenic mammals. Lower molars appear not to be particularly informative for critical early tribosphenid taxa (as illustrated by the case of *Holoclemensia*, earlier suggested to be marsupial¹⁷, but more closely resembling eutherians based on referred lower molars; Fig. 3), indicating that taxa known only from molar structure must be interpreted cautiously. The relationship of *Montanalestes* to other early eutherians remains uncertain because available data produce ambiguous results.

The earliest generally accepted eutherians are from the Early and early Late Cretaceous of Asia^{8,10,16,18}. Previous reports of Early Cretaceous Eutheria in North America¹⁷ are based on extremely fragmentary specimens and have been controversial because of differing interpretations of tooth formula and specimen association⁷. Uncontested eutherians do not appear in North America until the early Campanian (about 80 Myr)¹⁹. By contrast, marsupials and presumed relatives were well established on the continent by the medial Cretaceous, about 100 Myr^{6,20}. These distributions have led to the suggestion that eutherians and marsupials arose in Eurasia and North America, respectively, and that North American eutherians are derivatives of Late Cretaceous immigration from Asia². Except for ungulates⁴, however, Late Cretaceous eutherians of Asia and North America represent distinct clades whose intercontinental relationships are problematic^{11,19}. If *Montanalestes* is related to Eutheria, as the balance of evidence indicates, then the continent of origin for the group is called into question: evidently, Eutheria enjoyed a far broader Early Cretaceous distribution (echoing that of the triconodont mammal *Gobiconodon*²¹) and an earlier evolutionary radiation than previously envisaged. An early presence of Eutheria in North America indicates that some of the continent's distinctive Late Cretaceous taxa may have evolved *in situ*, rather than having a proximal Asiatic origin—a theory to be tested by recovery of further faunas from the medial Cretaceous, where the record so far has been notoriously poor¹³. □

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Oldest playable musical instruments found at Jiahu early Neolithic site in China

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Excavations at the early Neolithic site of Jiahu^{1,2} in Henan Province, China have produced what may be the earliest complete, playable, tightly-dated multinote musical instruments. Jiahu was occupied from 7000 BC to 5700 BC, considerably antedating the well known Peiligang culture^{3–5}. Here we describe six exquisitely made complete flutes which were found in radiocarbon-dated excavation layers, along with fragments of perhaps 30 more. The

flutes are made from the ulnae of the red-crowned crane (*Grus japonensis* Millen) and have 5, 6, 7 and 8 holes. The best preserved flute has been played and tonally analysed. In addition to early musical artefacts, the archaeological record at Jiahu^{1,2} contains important information on the very foundations of Chinese society. We describe the archaeological characteristics of the Jiahu site, details concerning its dating, its place in the prehistory of the Chinese Neolithic, the ethnicity of its population and the results of a tonal analysis of a nearly 9,000-year-old musical instrument found there.

Jiahu lies in the 'Central Yellow River Valley'³ in mid-Henan Province, east of Mount Funiu and bounded by the flood plains of the Ni river to the south and the Sha river to the north. It was discovered by Zhu Zhi in 1962 but its significance was not fully appreciated until other sites related to the Peiligang culture^{3–5} had been excavated. Jiahu is an irregular ellipse, 275 m long (east–west) and 260 m wide (north–south). Below a modern agricultural layer of loess 0.3–1.0 m deep lies a layer of the Han Dynasty (206 BC–AD 220), and beneath this Neolithic layers which together are 0.5–0.9 m thick. Of Jiahu's 55,000 m², only 2,400 m² (4.4%) have been excavated, revealing 45 house foundations, 370 cellars, 9 pottery kilns, more than 300 graves and thousands of artefacts made out of bone, pottery, stone and other materials. There are three sub-periods at Jiahu; during the latest two the site shows distinct areas for residences, workshops and graves¹. The differential furnishing of the graves provides evidence for early social stratification. Jiahu appears to represent an organized, well established sedentary village of long duration in the very early Chinese Neolithic.

The dating of Jiahu is crucial. So far we have determined twenty ¹⁴C dates: nine from charcoal (three in each of the three sub-periods mentioned above), five from plant ash, four from human bone, one from a whole fruit pit and one from a broken grain of carbonized rice. The conventional ¹⁴C ages range from 7,017 to 8,285 ¹⁴C years BP. After dendrochronological correction the corresponding range is 7,700 to 9,000 calendar years BP or nearly 5700 to 7000 cal. (calibrated) BC. The three sub-periods are dated as follows: the oldest is 6600–7000 cal. BC; the second oldest 6200–6600 cal. BC; and the third ~5700–6200 cal. BC. Thus, Jiahu spans some 1,300 years. If this range of dates is borne out by subsequent research, then Jiahu represents a Neolithic cultural phase distinctly earlier at its inception than the Peiligang culture, where the dates of many of the sites range from 5100 BC to 6300 BC^{3–5}. On the basis of these dates, and considering the repertoire of ceramic shapes and stone tools¹, we would tentatively characterize Jiahu as a culture parallel to, overlapping in duration, and very possibly related to, the Peiligang. The same might apply to the site of Houli in the eastern Yellow River Valley (north-central Shandong Province), dated 5000 BC to 6200 BC³. For the ¹⁴C determinations, see Supplementary Information.

A careful study of the bones of 400 individuals removed from more than 300 graves indicates that the Jiahu ethnic group may be identified with the North Asian Mongolian group, and also with the Xiwanggang and Miaodigou groups in Henan Province and the Dawenkou, Yedian and Xixiahou groups that were later found in Shandong Province. The range of male heights was from 170 to 180 cm. In the late Palaeolithic Zhoukoudian Cave, 'unspecialized'

Table 1 Analysis of intervals of flute M282:20

Location of interval	Average value in cents ¹⁴	Musical description
Between hole 1 and hole 2	284	Minor third
Between hole 2 and hole 3	244	Slightly larger than major second (a whole tone)
Between hole 7 and tube sound	260	Slightly smaller than minor third, slightly larger than a whole note.